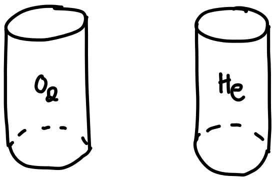
Taylor Larrechea
Dr. Middleton
PHYS 230 HW 5

HW 5

CQ1. Consider two identical containers, one is filled with helium gas and the other is filled with oxygen gas. Both gases are found to have the same root-mean-square speeds. How do their temperatures compare? Answer quantitatively!



$rms_{He} = rms_{O_2}$ T ?

$$\sqrt{\frac{3K_bT_{O_2}}{m_{O_2}}} = \sqrt{\frac{3K_bT_{He}}{m_{He}}}$$

$$\frac{3K_bT_{O_2}}{m_{O_2}} = \frac{3K_bT_{He}}{m_{He}}$$

$$\frac{m_{He}}{m_{O_2}} = \frac{T_{He}}{T_{O_2}}$$

$$\frac{4u}{32u} = \frac{T_{He}}{T_{O_2}} \quad \therefore \quad \frac{32u}{4u} = \frac{T_{O_2}}{T_{He}} = 8:1$$

$\epsilon_{avg} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}K_bT$

$m_{He} = 4u$
$m_{O_2} = 32u$

$mv_{rms}^2 = 3K_bT$
$v_{rms} = \sqrt{\frac{3K_bT}{m}}$

The temperature of oxygen is 8 times larger than that of helium due to its bigger mass

$T_{O_2} : T_{He} = 8:1$

CQ2. The average kinetic energy of the molecules in an ideal gas increases with the volume remaining constant. Which of the following statements *must* be true?

a) The pressure increases and the temperature stays the same.

b) The number density decreases.

c) The temperature increases and the pressure stays the same.

d) Both the pressure and the temperature increase.

d.)

$PV = nRT$ $\quad n = \frac{PV}{RT}$

$E_{th} = W + Q \quad W = 0 \quad \therefore \quad E_{th} = Q$

Constant volume $\therefore$ $Q = nC_V\Delta T$

$E_{th} = K_{micro} = Q = nC_V\Delta T = \frac{3}{2}NK_BT$

$\epsilon_{Avg} = \frac{3}{2}K_BT$

if $\epsilon_{Avg} \uparrow \therefore T \uparrow$

$V = V \quad T\uparrow$

$P = \frac{nRT}{V} \quad \therefore \quad P\uparrow$

$P\uparrow$

$PV = NK_BT$

$\frac{P}{K_BT} = \frac{N}{V} \qquad \frac{N}{V} = \frac{N}{V}$

d.) Both the pressure and temperature increase.

CQ3. The rms speed is the

a) speed at which all the gas molecules move.

b) speed of a molecule with the average kinetic energy.

c) average speed of the gas molecules.

d) maximum speed of the gas molecules.

c.)

CQ4. If the temperature of an ideal gas is doubled and the pressure is held constant, the rms speed of the molecules

a) remains unchanged.

b) is 2 times the original speed.

c) is $\sqrt{2}$ times the original speed.

d) is 4 times the original speed.

c.)

$PV = nRT$ $\quad E_{Avg} = \frac{1}{2}m(v^2)_{avg} = \frac{1}{2}mv_{rms}^2$ $\quad E_{Avg} = \frac{3}{2}k_BT$ $\quad PV = Nk_BT \;\vdots\; k_BT = \frac{PV}{N}$

$PV = Nk_BT$

$\frac{PV}{T} = Nk_B$ $\quad \frac{V_0}{T_0} = \frac{V_1}{T_1}$

$T_1 : T_0 = 2:1$ $\quad \frac{T_1}{T_0} = \frac{V_1}{V_0}$ $\quad \therefore V_1 : V_0 = 2:1$

$N = kg \cdot m/s^2$

$\frac{N/m^2 \cdot m^3}{kg \cdot \#} = \frac{Nm}{kg} = \frac{kg \cdot m/s^2 \cdot m}{kg} = m^2/s^2$

$\sqrt{m^2/s^2} = m/s$ ✓

$\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$

$\frac{1}{2}mv_{rms}^2 = \frac{3}{2}\left(\frac{PV}{N}\right)$

$mv_{rms}^2 = \frac{3PV}{N}$

$v_{rms} = \sqrt{\frac{3PV}{mN}}$

$k_BT = \frac{PV}{N}$

$P_0 = P_1,\ V_0 = \frac{1}{2}V_1,\ m_0 = m_1,\ N_0 = N_1$

$v_{Rms_0} = \sqrt{\frac{3PV_0}{mN}}$, $\quad v_{Rms_1} = \sqrt{\frac{3PV_1}{mN}} = \sqrt{\frac{6PV_0}{mN}}$

$v_{Rms_1} : v_{Rms_0} = \sqrt{2} : 1$

P1. The mean free path of nitrogen molecules is 8.0×10^{-8} m when the gas is held at a temperature of 0.0°C and a pressure of 1.0 atm. Calculate the diameter of the nitrogen molecules.

$$\lambda = \frac{L}{N_{coll}} = \frac{1}{4\sqrt{2}\pi(N/V)r^2}$$

$PV = NK_BT$

$\frac{N}{V} = \frac{P}{K_BT}$

2 sig figs

$P = 1.01\times10^5\, N/m^2$

$K_BT = 1.38\times10^{-23}\, J/K$

$T = 273\, K$

$\lambda = 8.0\times10^{-8}\, m$

$\frac{N}{V} = 2.68\times10^{25}\, m^{-3}$

$\lambda = 8.0\times10^{-8}\, m$

$$\frac{N}{V} = \frac{(1.01\times10^5 N/m^2)}{(1.38\times10^{-23} J/K)(273\ K)} = 2.68\times10^{25}\, m^{-3}$$

$$\lambda = \frac{1}{4\sqrt{2}\pi(N/V)r^2} \quad \therefore\ 4\sqrt{2}\pi(N/V)r^2 = \frac{1}{\lambda}$$

$$r^2 = \frac{1}{4\sqrt{2}\pi(N/V)(\lambda)} = \sqrt{\frac{1}{4\sqrt{2}\pi(N/V)(\lambda)}} \ \vdots$$

$m^{-3}(m) = \frac{m^3}{m} = m^2$

$\sqrt{m^2} = m$ ✓

$$r = \sqrt{\frac{1}{4\sqrt{2}\pi(N/V)(\lambda)}} = \sqrt{\frac{1}{4\sqrt{2}\pi(2.68\times10^{25} m^{-3})(8.0\times10^{-8} m)}} = 1.62\times10^{-10}\, m$$

$d = 2r \ \therefore\ d = 2(1.62\times10^{-10}\, m) = 3.24\times10^{-10}\, m$

$d = 3.24\times10^{-10}\, m$

P2. Consider a 5-particle gas of molecules with velocities given by

$$\begin{aligned}
\vec{v}_1 &= (15\hat{\imath} - 25\hat{\jmath} + 25\hat{k}) \text{ m/s} \\
\vec{v}_2 &= (20\hat{\imath} - 30\hat{\jmath} + 40\hat{k}) \text{ m/s} \\
\vec{v}_3 &= (-35\hat{\imath} + 20\hat{\jmath} - 10\hat{k}) \text{ m/s} \\
\vec{v}_4 &= (20\hat{\imath} - 30\hat{\jmath} - 30\hat{k}) \text{ m/s} \\
\vec{v}_5 &= (-20\hat{\imath} + 65\hat{\jmath} + 25\hat{k}) \text{ m/s}
\end{aligned}$$

Calculate the

a) average velocity,

b) the average speed, and

c) the root-mean-square speed of the gas particles.

2 sig figs

a.) $\sum v_x = 0 \quad v_x/5 = 0 \text{ m/s}$

$\sum v_y = 0 \quad v_y/5 = 0 \text{ m/s}$

$\sum v_z = 50 \quad v_z/5 = 10 \text{ m/s}$

$V_{Avg} = 10 \text{ m/s } \hat{k}$

b.) Average Speed $\quad V_{spd} = 51 \text{ m/s}$

$v_1 = \sqrt{(15)^2 + (25)^2 + (25)^2} = 38.4 \text{ m/s}$

$v_2 = \sqrt{(20)^2 + (30)^2 + (40)^2} = 53.8 \text{ m/s}$

$v_3 = \sqrt{(35)^2 + (20)^2 + (10)^2} = 41.5 \text{ m/s}$

$v_4 = \sqrt{(20)^2 + (30)^2 + (30)^2} = 46.9 \text{ m/s}$

$v_5 = \sqrt{(20)^2 + (65)^2 + (25)^2} = 72.4 \text{ m/s}$

$V_{spd} = \dfrac{v_1 + v_2 + v_3 + v_4 + v_5}{5} = 50.6 \text{ m/s}$

$V_{sp} = 51 \text{ m/s}$

c.) rms : $\quad V_{rms} = 52 \text{ m/s}$

$v_1 = 15^2 + 25^2 + 25^2 = 1475 \text{ m}^2/\text{s}^2$

$v_2 = 20^2 + 30^2 + 40^2 = 2900 \text{ m}^2/\text{s}^2$

$v_3 = 35^2 + 20^2 + 10^2 = 1725 \text{ m}^2/\text{s}^2$

$v_4 = 20^2 + 30^2 + 30^2 = 2200 \text{ m}^2/\text{s}^2$

$v_5 = 20^2 + 65^2 + 25^2 = 5250 \text{ m}^2/\text{s}^2$

$v_{rms} = \left[\dfrac{v_1 + v_2 + v_3 + v_4 + v_5}{5}\right]^{1/2} = 52.05 \text{ m/s}$

$V_{rms} = 52 \text{ m/s}$

P3. A container of gas has a density of 1.24×10^{-5} g/cm^3 when the pressure of the gas is 1.01×10^3 Pa and its temperature is 0.00°C.

a) Calculate the root-mean-square speed of this gas?

b) Calculate the molar mass of the gas and identify the gas.

$\rho = 1.24 \times 10^{-5}\, g/cm^3$
$P = 1.01 \times 10^3\, N/m^2$
$T = 273\, K$

$P = \frac{F}{A} = \frac{1}{3}\left(\frac{N}{V}\right) m v_{rms}^2$
$PV = \frac{2}{3} N E_{avg}$
$PV = N k_B T$ $\quad PV = nRT$

$E_{avg} = \frac{1}{2} m v_{rms}^2$
$E_{avg} = \frac{3}{2} k_B T$

$n = \frac{N}{N_A}$ $\quad N = \frac{M}{m}$ $\quad n = \frac{M}{M_{mol}}$
$\rho = M/V$

a.) rms? $\quad \rho = \frac{N \cdot m}{V}$

$m = \rho\left(\frac{V}{N}\right)$

$m = \rho \cdot \frac{k_B T}{P}$

$\frac{N}{V} = \frac{P}{k_B T} \quad \therefore \quad \frac{V}{N} = \frac{k_B T}{P} = \frac{(1.38 \times 10^{-23} J/K)(273 K)}{1.01 \times 10^3 N/m^2} \approx 3.73 \times 10^{-24} \frac{m^3}{\#}$

$\rho = 1.24 \times 10^{-5} \frac{g}{cm^3} \cdot \frac{0.001 kg}{g} = 1.24 \times 10^{-8} \frac{kg}{cm^3} \cdot \frac{(1 cm)^3}{(0.01 m)^3} = 1.24 \times 10^{-2} kg/m^3$
$\rho = 1.24 \times 10^{-2} kg/m^3$

$k_B = 1.38 \times 10^{-23} J/K$
$T = 273 K$
$P = 1.01 \times 10^3 N/m^2$

$m = (1.24 \times 10^{-2} kg/m^3) \cdot (3.73 \times 10^{-24} m^3/\#) = 4.625 \times 10^{-26} kg$

$\frac{1}{2} m v_{rms}^2 = \frac{3}{2} k_B T$

$v_{rms}^2 = \frac{3 k_B T}{m}$

$v_{rms} = \sqrt{\frac{3 k_B T}{m}} = \sqrt{\frac{3(1.38 \times 10^{-23} J/K)(273 K)}{4.625 \times 10^{-26} kg}} = 494.3\, m/s$

$v_{rms} = 494\, m/s$

$m = 4.625 \times 10^{-26} kg$
$u = 1.661 \times 10^{-27} kg$
$\frac{m}{u}$ tells number of atoms in substance
$\frac{m}{u} = 27.8 \approx 28u$

b.) Element

$m = 4.625 \times 10^{-26} kg$
$u = 1.661 \times 10^{-27} kg$

$\frac{m}{u}$ tells number of atoms in gas

$\frac{m}{u} = 27.8 \approx 28u$

Since there are 28 nucleons in this gas, the element is Nitrogen

Nitrogen $\parallel$ N_2

P4. 8.5 g of oxygen gas, with an initial temperature of 325○C is placed in thermal contact with 3.5 g of helium gas, which has an initial temperature of 23○C.

a) Calculate the initial and final thermal energies of each gas.

b) How much heat is transferred, and in which direction?

c) Calculate the final temperature.

$O_2 = 1$ $\quad m_1 = 8.5\times10^{-3}\,kg$ $\quad T_{1i} = 598\,K$ $\quad n_1 = \frac{M_1}{m_1} = \frac{8.5\times10^{-3}\,kg}{32\times10^{-3}\,kg} = 0.265\,mol$ $\quad n_2 = \frac{3.5\times10^{-3}\,kg}{4\times10^{-3}\,kg} = 0.875\,mol$

$He = 2$ $\quad m_2 = 3.5\times10^{-3}\,kg$ $\quad T_{2i} = 296\,K$

a.) $E_{1i} = \frac{5}{2} n_1 R T_{1i} = \frac{5}{2}(0.265\,mol)(8.31\,J/mol\,K)(598\,K) = 3292.91\,J$ $\qquad E_{tot} = 6520.65\,J$

$E_{2i} = \frac{3}{2} n_2 R T_{2i} = \frac{3}{2}(0.875\,mol)(8.31\,J/mol\,K)(296\,K) = 3228.44\,J$

$E_{1f} = \frac{n_1}{n_1+n_2} E_T = \frac{(0.265\,mol)}{(0.265\,mol + 0.875\,mol)}(6520.65\,J) = 1515.77\,J$

$E_{2f} = \frac{n_2}{n_1+n_2} E_T = \frac{(0.875\,mol)}{(0.265\,mol + 0.875\,mol)}(6520.65\,J) = 5004.88\,J$

O_2 :	He
$E_i = 3290\,J$	$E_i = 3230\,J$
$E_f = 1520\,J$	$E_f = 5000\,J$

b.) $Q = nC\Delta T$ $\qquad n_1 = 0.265\,mol$ $\quad n_2 = 0.875\,mol$

$Q_1 = n_1 C_1 \Delta T_1$ $\qquad C_1 = 20.9\,J/mol\,K$ $\quad C_2 = 12.5\,J/mol\,K$

$Q_2 = n_2 C_2 \Delta T_2$ $\qquad \Delta T_1 = -195.5\,K$ $\quad \Delta T_2 = 101.5\,K$

$Q_1 = (0.266\,mol)(20.9\,J/mol\,K)(-199.5\,K) = -1107.5\,J \approx -1110\,J$

$Q_2 = (0.875\,mol)(12.5\,J/mol\,K)(101.5\,K) = 1110.16\,J \approx 1110\,J$

1110 J of heat are transferred from Oxygen to helium

c.) $\Sigma Q = 0 : \quad Q_{BT} + Q_P = 0$

$Q_1 + Q_2 = 0$

$Q_1 = n_1 C_1 \Delta T_1 = n_1 C_1 (T_f - 598\,K)$

$Q_2 = n_2 C_2 \Delta T_2 = n_2 C_2 (T_f - 296\,K)$

$C_1 = 20.9\,J/mol\,K$ $\quad C_2 = 12.5\,J/mol\,K$

$n_1 = 0.266\,mol$ $\quad n_2 = 0.875\,mol$

$n_1 C_1 T_1 - n_1 C_1 (598\,K) + n_2 C_2 T_1 - n_2 C_2 (296\,K) = 0$

$T_1 (n_1 C_1 + n_2 C_2) = n_1 C_1 (598\,K) + n_2 C_2 (296\,K)$

$T_1 = \frac{n_1 C_1 (598\,K) + n_2 C_2 (296\,K)}{n_1 C_1 + n_2 C_2}$

$T_1 = \frac{(0.266\,mol)(20.9\,J/mol\,K)(598\,K) + (0.875\,mol)(12.5\,J/mol\,K)(296\,K)}{(0.266\,mol)(20.9\,J/mol\,K) + (0.875\,mol)(12.5\,J/mol\,K)} = 397.5\,K$

$T_1 \approx 398\,K$

$T_1 = 398\,K \;||\; 125\,°C$

P5. A monatomic gas is isochorically heated until the gas temperature triples. Do each of the following quantities change? If so, do each increase or decrease, and by what factor. If not, why not?

a) The root-mean-square speed.

b) The mean free path.

c) The thermal energy of the gas.

d) The molar specific heat at constant volume.

a.) V_{rms} ?

$V_{rms} = \sqrt{\frac{3K_BT}{M}}$ $\quad V_0 = \sqrt{\frac{3K_bT}{m}}$ $\quad V_1 = \sqrt{\frac{9K_bT}{m}}$

$V_1 : V_0 = \sqrt{3} : 1$

The V_{rms} increases by a factor of $\sqrt{3}:1$

$V_1 : V_0 = \sqrt{3} : 1$

b.) $\lambda = \frac{1}{4\sqrt{2}\pi(N/V)r^2}$ $\quad PV = NK_BT$ $\quad \frac{N}{V} = \frac{P}{K_BT}$

when temp triples $\left(\frac{N}{V}\right)$ decreases by $\left(\frac{1}{3}\right)$

$\therefore \lambda_1 = \frac{1}{4\sqrt{2}\pi(^{1N}/_{3V})r^2} = 3 \cdot \frac{1}{4\sqrt{2}\pi(N/V)r^2}$

$\lambda_1 = 3\lambda_0$

The wavelength triples!

$\lambda_1 = 3\lambda_0$

c) $E_{th} = W + Q$ $\quad W = 0$ $\quad \therefore E_{th} = Q$

$E_{th} = \frac{3}{2}nRT$ $\quad E_0 = \frac{3}{2}nRT$ $\quad E_1 = \frac{3}{2}nR(3T) = \frac{9}{2}nRT$

$E_1 : E_0 = {}^9\!/_2\, nrT \,/\, \frac{3}{2}nrT = 3$

The thermal energy triples because the temperature triples with no work done

$E_{th_1} : E_{th_0} = 3:1$

d.) $Q = nC_V\Delta T$ $\quad \therefore C_V = \frac{Q}{n\Delta T}$ $\quad C_{V_0} = \frac{Q}{n\Delta T}$ $\quad C_{V_1} = \frac{Q}{n3\Delta T}$

The molar specific heat is $\frac{1}{3}$ what it is originally

$C_{V_1} = \frac{1}{3}C_{V_0}$

P6. 1.00 mol of helium gas starts at an initial state A, which is characterized by a pressure of 1.00 atm and a temperature 300.K. The gas undergoes an *isochoric heating* until it reaches a state B where the gas reaches a temperature of 600.K. The gas then undergoes an *adiabatic expansion* until it reaches a state C where the gas reaches it's initial pressure. Finally, the gas undergoes an *isobaric compression*, which brings the gas back to its initial state A .

a) Calculate the pressure and volume of the gas at states B and C.

A, B, and C, respectively.

b) Draw a pV diagram showing this process. This diagram needs to include axes labels and an arrow indicating the direction traversed between the initial and final points on the pV curve. Also, indicate the temperature at each point.

c) Calculate the heat, Q, work done on the gas, W, and thermal energy change, ΔE_{th} for the gas as it goes through *each* of the three aforementioned processes.

a.)

State A : P? V?

$PV = nRT$

$n_A = 1.00$ mol

$R = 8.31$ J/mol K

$T_A = 300$ K

$P = 1.01 \times 10^5$ Pa

$$V_A = \frac{n_A R T_A}{P_A} = \frac{(1.00\,\text{mol})(8.31\,\text{J/mol K})(300\,\text{K})}{1.01 \times 10^5\,\text{N/m}^2} = 2.468 \times 10^{-2}\,\text{m}^3$$

$$\boxed{\text{State A}: \; V_A = 2.47 \times 10^{-2}\,\text{m}^3 \quad P_A = 1.01 \times 10^5\,\text{N/m}^3}$$

State B : P & V?

$n_B = 1.00$ mol $\quad R = 8.31$ J/mol K

$T_{0B} = 300$ K $\quad T_{1B} = 600$ K

$P_{0B} = 1.01 \times 10^5$ Pa $\quad P_{1B} = 2.02 \times 10^5$ Pa

$V_0 = V_1 = 2.47 \times 10^{-2}\,\text{m}^3$

$PV = nRT \qquad nR = \frac{PV}{T}$

$$\frac{P_{0B} V_{0B}}{T_{0B}} = \frac{P_{1B} V_{1B}}{T_{1B}}$$

$$\frac{P_{0B}}{T_{0B}} = \frac{P_{1B}}{T_{1B}} \quad \therefore \quad P_{1B} = \frac{P_{0B} T_{1B}}{T_{0B}} = \frac{(1.01 \times 10^5\,\text{Pa})(600\,\text{K})}{(300\,\text{K})} = 202{,}000\,\text{Pa}$$

$$\boxed{\text{State B}: \; V_B = 2.47 \times 10^{-2}\,\text{m}^3 \quad P_B = 2.02 \times 10^5\,\text{N/m}^2}$$

State C : P & V?

$P_{0C} = 2.02 \times 10^5$ Pa $\quad P_{1C} = 1.01 \times 10^5$ Pa

$V_{0C} = 2.47 \times 10^{-2}\,\text{m}^3 \quad V_{1C} = 3.74 \times 10^{-2}\,\text{m}^3$

$T_{0C} = 600$ K $\quad T_{1C} = 454$ K

$E_{th} = W \quad \therefore \quad P_1 V_1^{\gamma} = P_0 V_0^{\gamma} \qquad \gamma = 1.67$

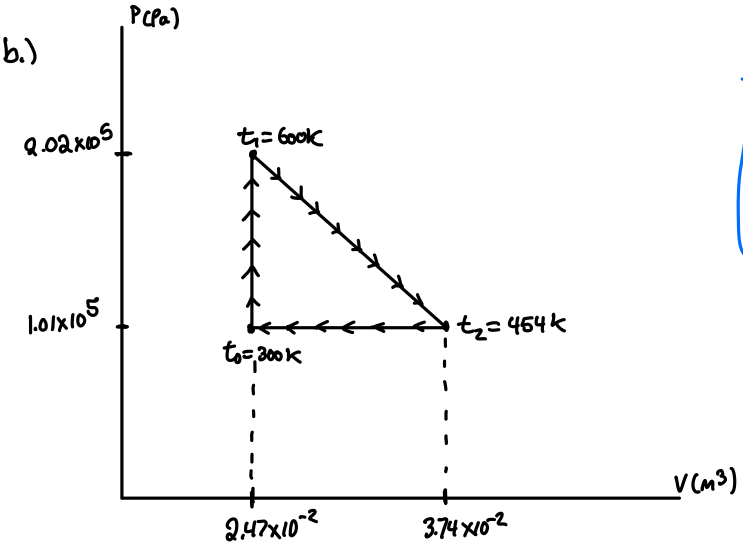
$$V_1^{\gamma} = \frac{P_0 V_0^{\gamma}}{P_1}$$

$$V_1 = \left[\frac{P_0 V_0^{\gamma}}{P_1}\right]^{1/\gamma} = \left(\frac{2.02 \times 10^5\,\text{N/m}^2 (2.47 \times 10^{-2}\,\text{m}^3)^{1.67}}{1.01 \times 10^5\,\text{N/m}^2}\right)^{1/1.67} = 3.74 \times 10^{-2}\,\text{m}^3$$

$$\frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1} \qquad T_1 = \frac{P_1 V_1 T_0}{P_0 V_0} = \frac{(1.01 \times 10^5\,\text{Pa})(3.74 \times 10^{-2}\,\text{m}^3)(600\,\text{K})}{(2.02 \times 10^5\,\text{Pa})(2.47 \times 10^{-2}\,\text{m}^3)} = 454.3\,\text{K}$$

$$\boxed{\text{State C} \quad V_c = 3.74 \times 10^{-2}\,\text{m}^3 \quad P_c = 1.01 \times 10^5\,\text{Pa}}$$

b.)



	A	B	C
P(Pa)	1.01×10^5	2.02×10^5	1.01×10^5
$V(m^3)$	2.47×10^{-2}	2.47×10^{-2}	3.74×10^{-2}
T(K)	300	600	454

c.) A → B Isochoric ∴ $W=0$

$\Delta E_{th} = Q$

$\Delta E_{th} = nC_V\Delta T = (1.00\,mol)(12.5\,J/mol\,K)(300\,K) = 3750\,J$

$n = 1.00\,mol$

$C_V = 12.5\,J/mol\,K$

$\Delta T = 300\,K$

$\Delta E_{th} = Q$

$\Delta E_{th} = 3750\,J$ ∴ $Q = 3750\,J$

A → B
$\Delta E_{th} = 3750\,J$
$Q = 3750$

B → C Adiabatic $Q=0$

$\Delta E_{th} = W + Q = nC_V\Delta T$

$\Delta E_{th} = W = nC_V\Delta T$

$n = 1.00\,mol$

$C_V = 12.5\,J/mol\cdot K$

$\Delta T = -146\,K$

$\Delta E_{th} = nC_V\Delta T = (1.00\,mol)(12.5\,J/mol\,K)(-146\,K) = -1825\,J$

$\Delta E_{th} = W = -1825\,J$

B → C
$\Delta E_{th} = -1825\,J$
$W = -1825\,J$

C → A Isobaric

$W = -P\Delta V$

$Q = nC_P\Delta T$

$W = -P\Delta V = -(1.01\times10^5\,Pa)(-1.27\times10^{-2}\,m^3) = 1282.7\,J$

$P = 1.01\times10^5\,Pa$

$\Delta V = -1.27\times10^{-2}\,m^3$

$W + Q = -1920\,J$

$Q = nC_P\Delta T = (1.00\,mol)(20.8\,J/mol\cdot K)(-154\,K) = -3203.2\,J$

$n = 1.00\,mol$

$C_P = 20.8\,J/mol\,K$

$\Delta T = -154\,K$

$\Delta E_{th} = -1920\,J$
$W = 1280\,J$
$Q = -3200\,J$